P-230: Novel Electrical-Chemically Polished Stainless Steel Anode Organic Light Emission Device with Long Lifetime at High Luminance for Flexible Lighting

Xiaoming Yu, Jiaxin Sun, Xiuling Zhu, Man Wong and Hoi Sing Kwok
Center for Display Research, Electronic and Computer Engineering Department,
Hong Kong University of Science and Technology, Clear Water Bay, Hong Kong

Abstract:

Stainless Steel (s.s.) sheet substrate was electrical-chemically polished. Afterwards its average surface roughness reached 1.93nm. Then Organic Light Emission Devices (OLEDs) were fabricated on it with Alq_3 *as the light emission material (EM) (called Devices SSA). So high-thermal-conductive s.s. was made use of directly as anode in Devices SSA. Lighted at initial luminance intensity 1135 cd/*m^2*, Devices SSA decayed to its half luminance after 18 hours (hrs) in the vacuum which has pressure of* $5X10^{-3}$ *Pa. At the same time, top emission OLEDs with evaporated aluminum anode on glass (called Devices AA) were fabricated with the same EM. Devices AA have 20.5 hrs half lifetime but much lower initial luminance intensity 296cd/*m^2*, as measured in the same vacuum condition. The maximum luminance (*L_{max}*) of Devices SSA is 61,200cd/*m^2*, which is 2.3 times as high as* L_{max} *of Devices AA. In this paper, Device SSA with s.s. substrate thickness 0.05mm and bending radius 2mm is demonstrated. It indicates a bright future of flexible lighting application. White OLEDs on this substrate is being researched and longer lifetime could be achieved soon under better condition.*

Keywords:

electrical-chemically polishing, stainless steel, OLEDs, lighting

1. Introduction

One big advantage for OLEDs being used as lighting source is: its emitted light could be tuned to any desired color and any lighting intensity. Since interest in organic electronics stems from the ability to deposit organic films on a variety of very-low-cost substrates, the future success of OLEDs will depend on capturing its low-cost lighting potential through the innovative fabrication of devices on inexpensive, large-area substrates[1]. Compared with glass substrate, metal sheet substrates are much better for their higher thermal conductivity. It's good for OLEDs' lighting, especially when OLEDs are working under high luminance intensity and generating large quantities of heats. If the generated heats were excluded from the devices in time, OLEDs could endure much longer lifetimes under higher luminance.

Metal substrates are used in metal top emission organic light emission diodes (MTOLEDs), which are promising candidates in developing OLEDs' luminance sources, especially in case of large area lighting sources. MTOLEDs could be widely used in ceiling lighting illuminator and automotive application in the future.

High work-function metals such as silver, gold and platinum could be used as good anodes in top emission OLEDs (TOLEDs) for their good hole injection ability. But it's expensive to apply sheets of them as substrates. S.S. was investigated in this paper. S.S. attracts us firstly for its low cost, secondly for its high thermal conductivity. And after surface electrical-chemically polishing, high quality surface could be obtained with high reflection and extremely low surface roughness.

2. Experiments

Stainless steel has good flexibility if sheets' thickness is under 0.1mm. This characteristic permits ultrathin stainless steel foil [2, 3, 4] being developed as flexible OLEDs' (FOLEDs) substrate. Ultrathin glass [5, 6], plastic films [7, 8, 9, 10, 11], and copolymer substrate [12, 13] were investigated as flexible substrate of OLEDs. But in these methods, stainless steel was usually coated with an insulating layer to achieve low surface roughness good enough for OLEDs. However, insulating layers prevent heat from radiating off the substrates. In this paper electrical-chemical method was applied in polishing s.s. sheet to get TOLEDs substrate with extremely low surface roughness and high reflectivity.

Type 304 S.S. was chosen as the substrate in MTOLEDs. The sheets with 1mm thickness were purchased from McMaster Company and the sheets with 0.05 thickness came from Alfa Aesar Co.. Electrical-chemical polishing method was applied on s.s. before devices fabrication. The polishing solution was mixed with acid (HNO_3) 1.41 g/cm^3 12.95ml, sulfuric acid (H_2SO_4)1.84 g/cm^3 83ml, phosphoric acid (H_3PO_4)1.68 g/cm^3 89ml, ethanolamine ($NH_3CH_2CH_2OH$) 0.33mol/L 4ml and H_2O 61ml. This solution was heated up to 80ºC. One piece of platinum was used as cathode and s.s. sample was polished at anode side. After polishing process, mean roughness of polished surface reaches 1.93nm, as observed from Atomic Force Microscopy (AFM) observation. And the mean reflectivity of the polished s.s. is around 60% over the whole visible spectrum.

At the same time, the top emission OLEDs (TOLEDs) with aluminum anode evaporated on bare glass were also fabricated as the control devices for investigated. Aluminum anode has extremely high reflectivity > ~90% and device with aluminum anode has best stability among kinds of TOLED devices with various anodes. Aluminum was evaporated on bare glass substrate with speed ~4.0Å/s and has mean roughness of 3.37nm, a little higher than the mean roughness of previous electrical-chemically polished s.s. anode surface.

Two TOLEDs were fabricated. They were device with s.s. anode (Device SSA) and device with aluminum anode (Device AA).

On above metal anodes, the devices' structures were composed of 3nm of vanadium pentoxide (V_2O_5) evaporated at a speed of ~0.5 Å/s. ~50nm HTL(N,N'-di(naphthalen-1-yl)-N,N'-diphenyl-benzidine (NPB)), 20nm EML (Tris-(8-hydroxy-quinolinato)-aluminium (Alq3)) and 20nm ETL/HBL (2,9-Dimethyl-4,7-diphenyl-1,10-phenanthroline (BCP)) were thermal evaporated

ISSN/008-0966X/08/3903-2064-$1.00 © 2008 SID

with the speed around ~1.5 Å/s. Lastly, ~10nm calcium and ~22nm silver were deposited to form the compond cathode, with the evaporation speed of ~2--4Å/s. All the evaporating processes were held inside the high vacuum chamber with pressure under 2X10^{-4} Pa.

3. Results

The emission layer of the devices was formed by Tris-(8-hydroxy-quinolinato)-aluminium (Alq_3). The resonant peaks of lights emitted from these two kinds devices were both at 524nm. In Figure 1 we described the resonant wavelengths versus viewing angle, which was calculated as the observing angles from the forward emitting direction. Spectrum peak of the light emitted from Device SSA shifts from 524nm (at normal direction) to 516nm (at 80º). This shift is much less than the peak spectrum shift of Device AA, which changes from 524nm (at normal direction) to 500nm (at 80º). It indicates well that s.s. substrate devices can provide luminance sources with more uniformly angular distributed emission lights.

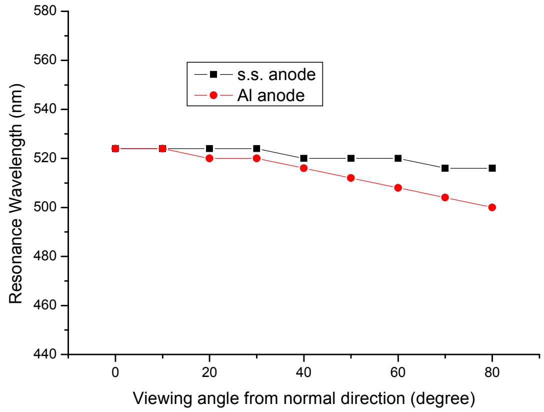
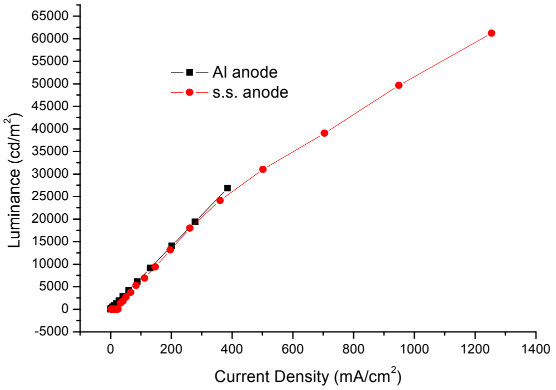


Fig 1. Resonance peak spectrums of Device SSA (■) and Device AA (●), varying with the observing angle

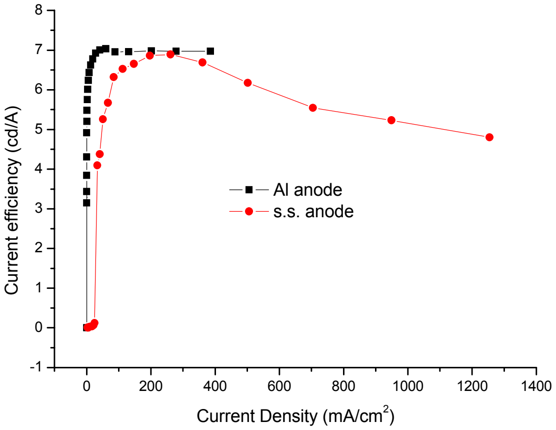
Thermal conductivity of s.s. substrate is much higher than the value of glass. Higher thermal conductivity is good for lengthening devices lifetime under higher initial luminance. The electrical- optical performances of Device SSA and Device AA were compared in Figure 2. The highest luminance was defined as the last brightness just before the devices burnt up by the increased currents. The highest luminance of Device SSA reached 61, 200 cd/m^2, much higher than that of Device AA, which is 26, 860 cd/m^2. And microcavity effect led the efficiencies of both the devices to very high values. The highest current efficiency was 6.69 cd/A for Device SSA and 7.03 cd/A for Device AA, much higher than the efficiency of ordinary standard ITO anode device ~3- 4 cd/A.

Lifetimes of the two devices were measured with Spectrum Meter PR650, in vacuum with pressure of 5X10^{-3}Pa. Device SSA was lighted at initial luminance 1135 cd/m^2. It took 18 hours for Device SSA to decay to half of the initial luminance. Device AA was lighted at 296cd/m^2 and it spent 20.5 hrs to burn down to the half initial value. So the two devices endured almost the same lifetime but at extremely different initial luminance. Evidently, due to the higher thermal conductivity of the substrate, Device SSA can be lighted with longer lifetime at much higher luminance for lighting application. The lifetimes' comparison experimental data and fitting data were presented in Figure 3.

Flexible lighting TOLEDs with 0.05mm polished s.s. substrate was demonstrated in Figure 4. The bending radius was 2mm. This would be an attracting flexible lighting sources application.



(a)



(b)

Fig 2. Electrical- optical properties of Device SSA (●) and Device AA (■): (a). Luminances VS Current Density, (b). Current efficiencies VS Current Density.

Stainless steel (s.s.) could be nominated as low costing metal substrate. More importantly, s.s. always consists of iron (Fe), chromium (Cr), nickel (Ni). These three components have the work functions 4.7eV, 4.5eV and 5.15eV, and have the thermal conductivities of 0.802 W/cmK, 0.937 W/cmK and 0.907 W/cmK, sequentially. The stainless steel was of components weight percent of Fe: Cr: Ni= 70: 19: 11, so the calculated thermal conductivity is 0.836 W/cmK and overall work-function is 4.7eV. The work function is very near the work function of Indium Tin Oxide (ITO), the conventional anode used in bottom emission OLEDs, which is 4.7eV. So as an anode, s.s. promises good hole injection probability in OLEDs.

Silicon dioxide is the most important component of glass and it has the thermal conductivity of 0.0105 W/cmK. Stainless steel has

80 times higher thermal conducting ability than glass for dispersing the generated heats. According to the lifetime measurement result, if the initial luminance value of Device SSA was converted to that value of Device AA, the lifetime of Device SSA would be almost 9.8 times of the lifetime of Device AA. Substrate thermal conductivity would be a great impact on OLED's performance.

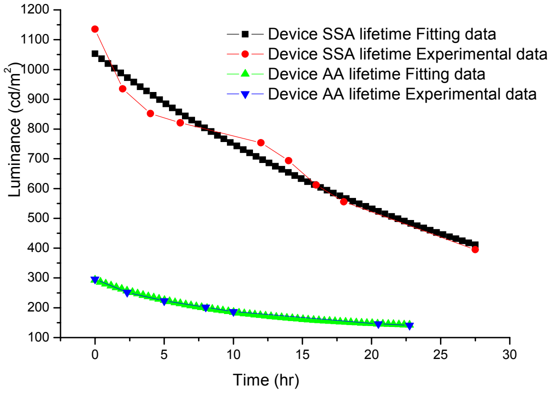


Fig 3. Lifetime measuring results and fitting data of Device SSA (■)(fitting data) (●) (experimental data)and Device AA (▲)(fitting data) (▼) (experimental data)

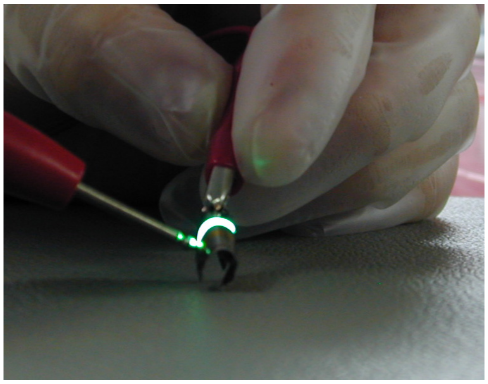


Fig 4. Stainless steel anode flexible lighting source with bending curvature radius 2mm

4. Summary

In summary, Stainless Steel (s.s.) sheet substrate was electrical-chemically polished to be the highly thermal conductive substrate of TOLEDs. Device SSA has much higher maximum luminance and much longer lifetime than Device AA. S.S. with thickness 0.05mm lighting device with the bending radius 2mm is demonstrated. It indicates a bright future of flexible lighting source. White OLEDs on this kind substrate is being researched and longer lifetime could be achieved soon under better condition. It's believed that white OLEDs with s.s. as anode could have a bright future.

5. Reference

[1] Stephen R. Forrest, Nature, Vol 428, 911, 2004

[2] Hyun Soo Shin, Jae Bon Koo, Jae Kyeong Jeong, Yeon gon Mo, Ho Kyun Chung, Jun Hyuk Cheon, Jong Hyun Choi, Kyu Man Kim, Ji Ho Hur, Seung Hyun Park, Sang Kyu Kim and Jin Jang, SID'05 54.4, Digest 1642, 2005

[3] Zhiyuan Xie, Liang-Sun Hung, Furong Zhu, Chemical Physics Letters 381, 691, 2003

[4] C.C. Wu, S.D. Theiss, G.Gu, M.H. Lu, J.C.Sturm, S.Wagner, and S.R.Forrest, IEEE Electron Device Letters, Vol. 18, No. 12, 609, 1997

[5] A.N. Krasnov, Appl. Phys. Lett. 80, 3853, 2002

[6] Mark Dai Joong Auch, Ong Kian soo, Guenther Ewald, Chua Soo-Jin, Tin Solid Films 417, 47, 2002

[7] G. Gustafsson, G.M. Treacy, Y. Cao, F. Klavetter, N.Colaneri, and A.J.Heeger, Synth. Met. 57, 4123, 1993

[8] G.gu, P.E.Burrows, S.Venkatesh, and S.R.Forrest, Opt. Lett. 22, 172, 1997

[9] J.O. Zhao, S.J.Xie,S.H.Han, Z.W.Yang, L.N.Ye.T.L. Yang, Phys. Stat.Sol. (a) 184, 233, 1992

[10] T.Uchida, S.Kaneta, M.Ichihara, m.Ohtsuka, S.Hoshi, S.Webster, R.Czerw and D.L.Carroll, IDW'04, OLEDp-19, Digest 1379, 2004

[11] Akira Sugimoto, Hideo Ochi, Soh Fujimura, Ayako Yoshida, Toshiyuki Miyadera, and Masami Tsuchida, IEEE Jour. of Selected Topics in Quantum Electronics, Vol 10, No 1, 107, 2004

[12] Yanqing Li, Li-Wei Tan, Xiao-Tao Hao, Kian Soo Ong, and Furong Zhu, Liang-Sun Hung, Appl. Phys. Lett. 86, 153508, 2005

[13] Hsin Her Yu, Shug-June Hwang, Kuo-Cheng Hwang, Optics communications 248, 51, 2005